DEVELOPMENT OF EXTENDED RANGE AND BLENDED CONTROL MODULE FOR PLUG-IN HYBRID AIR MOTORCYCLE

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ABSTRACT

Research and development in internal combustion engine shows variety of possibility. As the engine technology getting smarter and complex, simple concept of using power source from nature such as air is almost forgotten. In this project, an internal combustion engine using gasoline has gone through some modification with the aim of using compressed air as the source of power for some part of trips. This kind of technology called as air hybrid engine. Air hybrid engine is capable of utilizing the high pressure compressed air as power source to move pistons in engine cylinder. To control this system, a blended control module was developed by using an open-source Programmable Interface Controller (PIC) which is smaller and powerful microcontroller. Other components such as sensor also had been used in this project. The overall control that had been developed is a closed-loop control system where a closed-loop control system is one in which control action is dependent on the output and have feedback function. Main purpose of this project is to make an idea become alive. This project will mainly concerned on controlling the different mode of engine by using microcontroller PIC16F876A coupled with speed sensors. A program in MikroC is written and developed to communicate with the microcontroller according to plan sequences. A schematic design and simulation in Proteus Professional is created first to see whether it functioning or not before a prototype board can be developed. For purpose of voltage regulation, a single-pole double throw (SPDT) relays are used as "OUTPUT" signal from the sensor for the microcontroller. The "OUTPUT RELAY" is of the 5V SPDT powered from the switching output voltage 5V DC of the microcontroller. The application that is going to be developed must be in a low cost and a small scale basis. Subsequently, experimental simulation tests will be conducted to evaluate the response and accuracy behavior of the microcontroller before the control module can be developed. As for the result, a control module circuit prototype has been developed and it is ready to be tested with the engine.

ABSTRAK

Kajian dan perkembangan dalam bidang enjin pembakaran dalam menunjukkan pelbagai kemungkinan. Disebabkan teknologi enjin yang semakin pintar dan kompleks, konsep yang mudah dengan menggunakan sumber kuasa dari alam semula jadi seperti udara hampir dilupakan. Dalam projek ini, enjin pembakaran dalam yang menggunakan petrol telah melalui beberapa pengubahsuaian dengan tujuan untuk menggunakan udara termampat sebagai sumber kuasa untuk sebahagian perjalanan. Teknologi ini dipanggil sebagai enjin hibrid udara. Enjin hibrid udara mampu menggunakan udara termampat bertekanan tinggi sebagai sumber kuasa untuk menggerakkan omboh dalam silinder enjin. Untuk mengawal sistem ini, satu modul kawalan telah dibangunkan dengan menggunakan Programmable Interface Controller (PIC) yang lebih kecil dan ia merupakan mikropengawal yang berkuasa. Komponen lain seperti sensor juga telah digunakan dalam projek ini. Kawalan keseluruhan yang telah dibangunkan adalah sistem kawalan gelung tertutup di mana sistem ini adalah salah satu tindakan kawalan yang bergantung kepada output dan mempunyai fungsi maklum balas. Tujuan utama projek ini adalah untuk menjadikan sesebuah idea itu hidup. Projek ini terutamanya akan mengambil berat mengenai kawalan mod enjin yang berbeza dengan menggunakan mikropengawal PIC16F876A yang ditambah dengan sensor kelajuan. Satu program ditulis dan dibangunkan dengan menggunakan MikroC untuk berkomunikasi dengan mikropengawal untuk bergerak mengikut urutan pelan. Satu skema reka bentuk dan simulasi menggunakan Proteus Professional dicipta untuk melihat sama ada ia berfungsi atau tidak sebelum prototaip litar boleh dibangunkan. Bagi tujuan aturan voltan, relay (SPDT) digunakan sebagai isyarat "OUTPUT" daripada sensor untuk mikropengawal. "OUTPUT RELAY" adalah dari relay (SPDT) 5V yang berkuasa dari pensuisan voltan 5V DC. Aplikasi yang akan dibangunkan mestilah dalam kos yang rendah dan secara kecil-kecilan. Selepas itu, ujian simulasi eksperimen akan dijalankan untuk menilai tingkah laku dan ketepatan mikropengawal sebelum ia boleh dibangunkan. Hasilnya, satu litar prototaip modul kawalan telah dibangunkan dan ia sedia untuk diuji bersama enjin.

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LIST OF SYMBOLS

Kp	Controller Gains
Ki	Controller Gains
Kd	Controller Gains
u(t)	Control Signal
e(t)	Difference Between Desired and Actual Value (Control Error)
Vd	Displacement Volume
η	Efficiency
ΔH	Enthalpy Difference
Wi	Indicated Work
I_L	Load Current
D_P	Protection Diode
h_{FE}	Transistor Current Gain
Vs	Voltage Supply

LIST OF ABBREVIATIONS

AM	Air Motor
ANSI	American National Standards Institute
ATDC	After Top Dead Center
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
ECU	Electronic Control Unit
CB	Compression Braking
IMEP	Indicated Mean Effective Pressure
PHV	Pneumatic Hybrid Vehicle
CAD	Crank angle degrees
TDC	Top Dead Center
BDC	Bottom Dead Center
IVO	Intake Valve Open
IVC	Intake Valve Close
EVO	Exhaust Valve Open
EVC	Exhaust Valve Close
PID	Proportional Integral Derivative
COP	Coefficient of Performance
RPM	Revolution Per Minute
PCB	Printed Circuit Board
PIC	Programmable Interface Controllers
PWM	Pulse With Modulation
ISIS	Intelligent Schematic Input System

ARES	Advanced Routing and Editing Software
LCD	Liquid Crystal Display
CNC	Computer Numerical Control
THT	Through Hole Technology
SMT	Surface Mount Technology
ROM	Read Only Memory
RAM	Random Access Memory
EEPROM	Electrically Erasable Programmable Read-Only Memory
IDE	Integrated Development Environment
SPST	Single Pole Single Throw
SPDT	Single Pole Double Throw

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

In order to reduce emissions, fuel consumption is a main factor in the development of the automotive field nowadays and the hybridization of engines is a way to make this happened. The development of plug-in hybrid air engine will greatly reduce the petroleum use because this technology provides the potential to replace a significant portion of transportation petroleum consumption by using compressed air for part of the trips. A plug-in hybrid air engine allows the option of having the operation and range of conventional motorcycle on longer trips with the help of internal combustion engine.

The purpose of plug-in hybrid air engine is to make the motorcycle is no longer dependent on a single fuel source. One of the advantages of plug-in hybrid air engine is their capability to integrate the transportation and compressed air power generation systems in order to improve the efficiency, fuel economy, and reliability of both systems with some modification of the internal combustion engine. To ensure the optimum running for the motorcycle, an engine control module for the hybrid air engine was developed in order to communicate and control the actuators in the engine.

1.2 PROBLEM STATEMENT

In order to sustain the future of nature due to the increasing on exhaust emission, a hybrid system was developed since long years ago. However, hybrid system also has its significant problems where they require two propulsion systems, which take up space, add weight and greatly increase the cost. Thus, the development of hybrid system did not survive the continuity because the engine that simply powered by another propulsion such as air motor generator requires a big air tank for compression process, and at the same time it is also lacking in mileage and not so powerful compared to conventional internal combustion engine.

Another challenge is that the suitable control of the operation of the engine is necessary to achieve much of the efficiency benefits and to avoid drivability problems such as difficulty with transmission shifting to something as simple as starting the car, which was not possible with mechanical control only. The performance and emissions that today's engines deliver would be impossible without the electronic controls that manage everything from ignition and fuel delivery to every aspect of emissions control. Electronic controls make possible engines that deliver excellent good fuel economy and will limit the pollution. So, the development of a suitable control module for the hybrid air engine is essential because it has the ability to control some modified parts in engine to refill the tank with compressed air only when the amount of compressed air in the tank becomes too low and the process will continue to get the optimum range of journey.

1.3 OBJECTIVES

The objectives of this study are as follows:

a. To develop a blended control module for plug-in hybrid air engine using Proteus Professional and MikroC software.
b. To test the engine control module at the hybrid air engine.

1.4 SCOPE

The scope of this study are as follows:

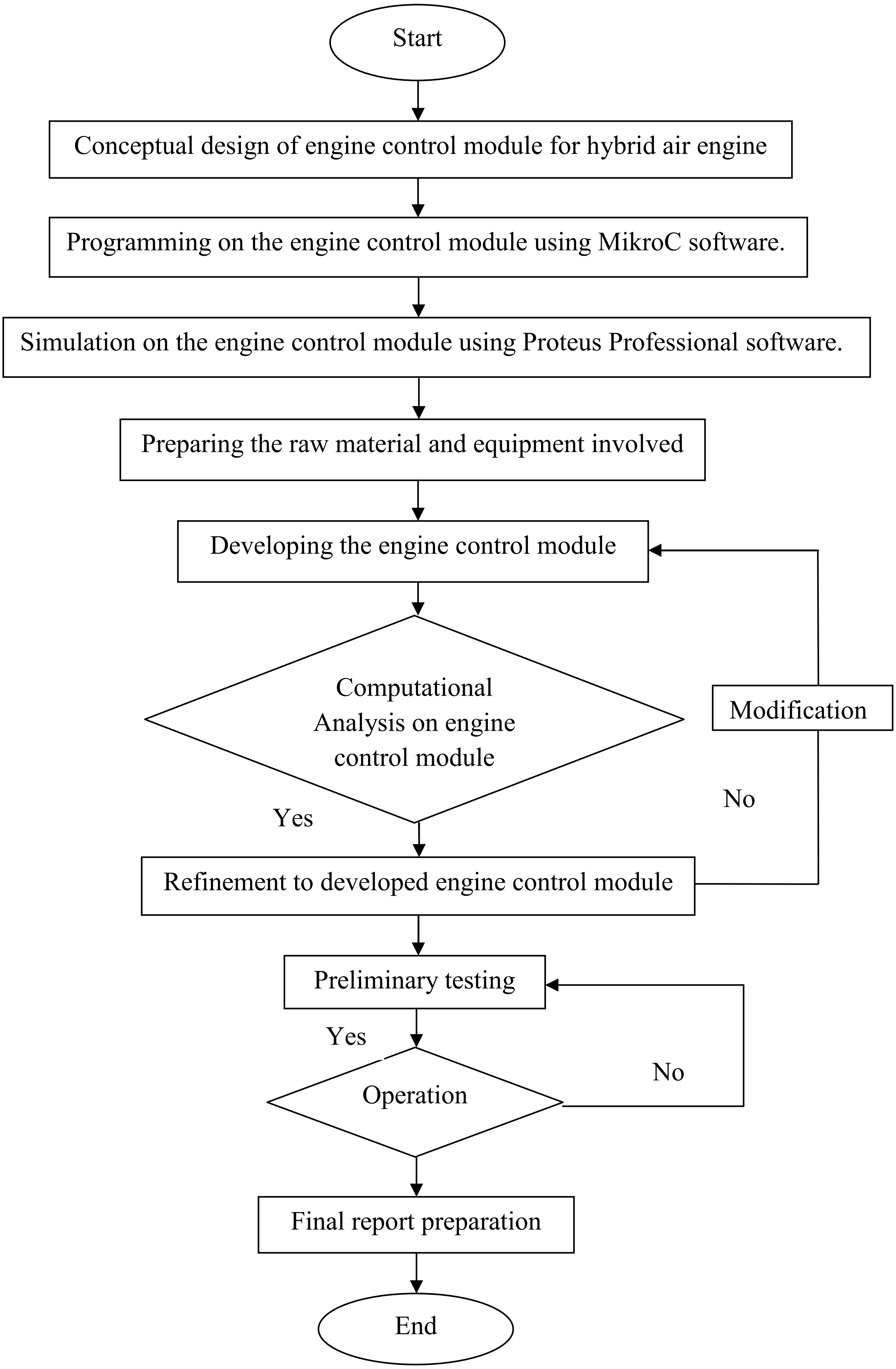
a. Conceptual design on the engine control unit for plug-in hybrid air engine.
b. Development of programming using MikroC software.

c. Simulation on the engine control unit using Proteus Professional software.
d. Preparing the raw materials and equipment involved.
e. Developing the engine control unit prototype.
f. Documentation.

1.5 HYPOTHESIS

At the end of the project, it was expected the prototype of engine control unit for plug-in hybrid air engine with blended mode provided is completed and ready for testing with the Subaru EA71 boxer engine, where this engine will serve as a potential and economic modification platform for hybrid engine development, which consists of internal combustion, air compression and innovated air powered cylinders integration.

1.6 FLOW CHART



1.7 GANTT CHART

Refer to APPENDIX A.

CHAPTER 2

LITERATURE REVIEW

2.1 AIR HYBRID VEHICLES

Hybrid electric vehicles (HEVs) have overcome production limits and are regarded as one of the most effective and feasible solutions to current environmental concerns. Hybrid electric vehicles (HEVs) use two sources of energy which are fossil fuel and electrochemical energy stored in batteries. They are usually comprised of an internal combustion engine (ICE) and an electric motor. Hybrid electric vehicles (HEVs) are able to store the vehicle's kinetic energy in the shape of electrochemical energy in a battery by running the electric motor as a generator. Despite the beneficiary improvements that this kind of vehicle provides, there are some serious concerns about hybrid electric vehicles (HEVs) performance (Amiri, 2009).

The hybrid electric vehicles (HEVs) Powertrain system is complex, which introduces a very complicated control problem and increases the maintenance cost of the vehicle. Using a battery in the Powertrain is also a problem for hybrid electric vehicles (HEVs) because battery-charging efficiency is highly dependent to the charging strategy (Amiri, 2009), and the state of charge of the battery which forms the basis of the vehicle control strategy cannot be precisely defined (I. Kim, 2006). In addition, hybrid electric vehicles (HEVs) are 10% to 30% heavier than ICE based vehicles (Guzzella, 2007).

Compared with a hybrid electric vehicle, an air hybrid based vehicle could provide a better efficiency with less complexity, weight and cost. In 1999, Schechter proposed the idea of an air hybrid engine for the first time. The idea evolved from the fact that the internal combustion engine can be run as a compressor and an air motor by changing the valve timing. Schechter has introduced a new cylinder head configuration in which there is an extra valve connecting the cylinder to an air tank, called the charging valve. This extra valve is active only when the engine works as a compressor or air motor. The valve sends the pressurized air from the cylinder to the air tank, and vice versa. He also studied the thermodynamic cycle of each mode. He reported more than a 50% reduction in fuel consumption by using the air hybrid engine in a 45 second driving cycle (Schecter, 1999).

In 2000, Schechter published his second paper. He used the same cylinder head configuration, but showed that by changing the valve timings, different engine loads can be achieved. He suggested that approximately 30 liter air-tank volume per 1000 kg of the vehicle mass is needed for a gasoline engine, and suggested a new definition of regenerative efficiency. Efficiency is defined as a fraction of the energy absorbed during braking that can be used in the subsequent acceleration. Based on a rough calculation, Schechter reported an efficiency of 74% for the regenerative braking system during the braking of a typical vehicle from an initial speed of 48 km/hr (Schecter, 2000). In 2007, Schechter patented the two-stage air hybrid configuration in which, some of the engine cylinders receive atmospheric air and after compression, transfer it to an intermediate air tank. Other cylinders receive compressed air from the intermediate tank and compress it further (Schecter, 2007).

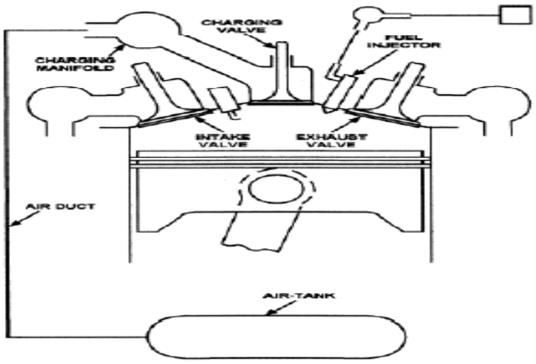


Figure 2.1: Schechter's proposed configuration

Source: Schecter (1999)

After these initial investigations on the air hybrid engine concept, there are research groups at different universities and research centers started investigating this new concept.

2.1.1 UCLA Research Group

In 2003, Tai, C in collaboration with Ford Motor Company proposed a new cylinder head configuration which enabled different modes of operation without adding an extra valve to the head. The group utilized four fully flexible camless valves for each cylinder, two intakes, and two exhausts. In this configuration, one of the intake valves is switchable, and connects either the intake manifold or air tank to the cylinder with a three-way valve. The group also optimized the valve timings according to the desired load, the tank pressure, and speed. The researchers claimed a 64% and 12% fuel economy improvement in city and highway driving, respectively. This improvement is reported to be partly due to using the camless valvetrain which permitted the engine to run unthrottled. They have provided no experimental results, but did use GT-POWER to simulate the proposed air hybrid engine configuration (Tai, C, 2003).

In 2008, they published their first experimental work on an air hybrid engine in collaboration with Volvo and Sturman Industries. They converted a six-cylinder diesel engine to an air hybrid engine utilizing a Sturman hydraulic camless valvetrain. They optimized the valve timings of the air motor (AM) and compression braking (CB) modes at two engine speed and three tank pressures, and implemented the obtained valve timings experimentally. They also reported the transient performance of the engine in switching from the compression braking (CB) to the air motor (AM) modes (Kang, 2008).

2.1.2 Lund Institute of Technology

In 2005, Andersson, M from the Lund Institute of Technology proposed a regenerative braking system with two tanks for a typical city bus. They concluded that the regenerative braking system with only one tank was not capable of producing high enough torque in the compression braking (CB) or air motor (AM) modes. Thus, the idea was to use a pressure tank as a substitute for the atmosphere as the supplier of the low-pressure air. The proposed configuration is shown in Figure 2.2. In this configuration, the engine works between a 600 liter low-pressure and a 145 liter high-pressure tank at different modes of operation. The engine cylinders are charged with the air from the low-pressure tank, which has a higher pressure compared to the ambient during braking. In the proposed configuration, the low-pressure tank must be replenished by an on-board compressor on a regular basis. They reported an average efficiency of 55% for the regenerative braking system and a 22% fuel consumption saving in a typical urban driving cycle obtained through simulations (Andersson, 2005).

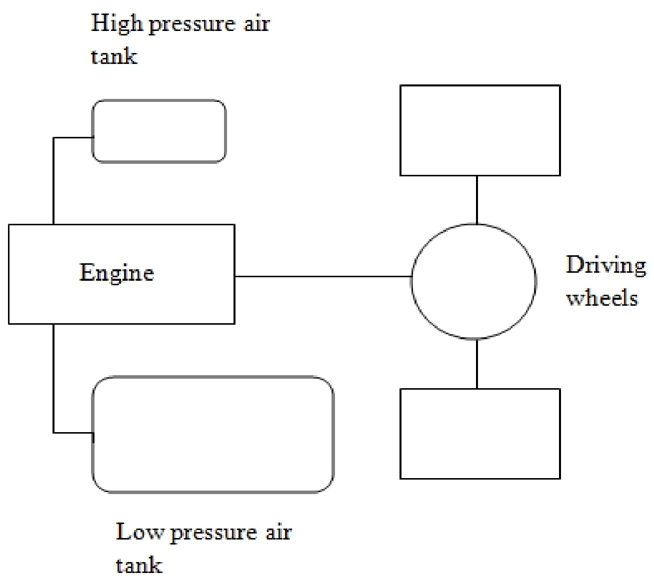


Figure 2.2: Air hybrid concept using two tanks

Source: Andersson (2005)

Later, in 2007, Trajkovic, S., from the same research group published the experimental results of an air hybrid engine. They converted a single-cylinder diesel engine to an air hybrid engine. Pneumatic valve actuators were used to make the air hybrid configuration possible. Two modes which are compression braking (CB) and air motor (AM), were tested and studied in this work. The Engine's Indicated Mean Effective Pressure (IMEP) and tank pressure were reported for different valve timings and engine speeds at the air motor (AM) and compression braking (CB) modes. A new definition of efficiency was also presented, based on the negative and positive Indicated Mean Effective Pressure (IMEP) at the compression braking (CB) and consequent air motor (AM) modes. An efficiency of 33% for the regenerative braking system was reported (Trajkovic, S, 2007).

They published their second investigation on the same air hybrid engine in 2008. They optimized the valve timings for the compression braking (CB) and air motor (AM) modes at various tank pressures. Additionally, they modified the tank valve diameter to increase the system efficiency. They showed that, by using a larger charging valve, the efficiency of the regenerative system, based on their definition of efficiency, could be increased to approximately 44%. They also compared the experimental results with GT-POWER results and found them to be in agreement.

In their next study, they validated an engine model in GT-Power by the experimental results and used the GT-Power model to study the effect of different parameters such as tank valve diameter and valve timings on pneumatic hybrid performance. In 2010, they published the driving cycle simulation results of their single-cylinder air hybrid engine. They chose a lower limit of 8 bars for the tank pressure and reported a reduction in the fuel consumption up to 30% in the Braunschweig driving cycle (Trajkovic, S, 2010).

2.1.3 National Taipei University of Technology

In addition to the information about air hybrid structures, there is also a totally different configuration of an air hybrid, proposed by Huang, K. D., Tzeng, S. C. in 2004. In this configuration, a typical internal combustion engine (ICE) was connected to a screw compressor and operates at the engine's most efficient point. Then, a pneumatic motor is driven by the compressed air to generate power. Thus, the main difference between the proposed air hybrid configuration and a series hybrid electric vehicle is that an air compressor replaces the generator, a pneumatic motor replaces the electric motor, and a high-pressure air tank replaces the battery. They achieved an 18% improvement in efficiency, compared with that of an internal combustion engine (ICE) based